

Experiments of Particle-Concentration Variability and Transport Associated with Turbulent and Convective Processes

Jeffrey D. Parsons

University of Washington, School of Oceanography, Seattle WA 98195-7940
phone: (206) 221-6627, fax: (206) 616-1247, email: parsons@ocean.washington.edu

Award Number: N000140310138

<http://www.ocean.washington.edu/people/faculty/parsons/research/cs.html>

LONG-TERM GOALS

To understand the mechanics of small-scale sediment-fluid interactions and how these processes affect transport and deposition of terrestrial material on active continental margins. Convective sedimentation (CS) and preferential concentration (PC) are two newly formulated processes that have the potential to change the way we think about delivery of riverine material to the continental shelf and beyond.

OBJECTIVES

- To analyze and publish the results of preliminary experiments, which found CS and PC in sediment-laden mixed layers.
- To formulate an empirical model that can predict sediment scavenging (i.e., effective removal rates) from stratified river plumes.
- To construct a facility capable of producing a stratified, sediment-laden mixed layer similar in both character and size as natural river plumes.
- To perform a series of experiments varying the inlet condition (and other variables) to identify the concentration required to produce a hyperpycnal flow.
- To use prototype equipment (developed in conjunction with a NSF-MRI grant) to attempt to identify the presence of PC and identify its role in particle settling in natural-scale turbulent shear layers.
- To develop predictive models of particle-concentration and sorting associated with the interaction of CS and PC.

APPROACH

Using a variety of instrumentation, we have sought to identify the environmental variables regulating the transport of sediment from the water column by turbulent, convective means. We rely heavily on laboratory experiments to constrain theoretical models. The experiments have thus far focused on the flow of a steady flow of fresh, sediment-laden fluid above a clear brine contained within a confined basin. The experiments have also provided an ideal testing ground for new field instrumentation (e.g., the FOBS-7 produced by D&A Instruments). Because the phenomena we intend to study have not been observed directly in the field (mostly due to instrumentation limitations), we will continue to develop new techniques that will enable measurements of these important, complex processes in natural settings.

Report Documentation Page			Form Approved OMB No. 0704-0188		
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 30 SEP 2003		2. REPORT TYPE		3. DATES COVERED 00-00-2003 to 00-00-2003	
4. TITLE AND SUBTITLE Experiments of Particle-Concentration Variability and Transport Associated with Turbulent and Convective Processes				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Washington, School of Oceanography,,Seattle,,WA,98195				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 6	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

WORK COMPLETED

- Identified the dimensionless variable regulating mixing-induced convective sedimentation and related it to the dimensionless vertical flux (Figure 1a).
- Used the scaling relationship discovered to accurately predict vertical fluxes measured during STRATAFORM (Figure 1b).
- Documented the presence and the amount of preferential concentration in both experiments of environmental suspensions (Figure 2a).
- Submitted for publication two papers associated with the aforementioned results.
- Designed and began construction on the laboratory that will be able, without significant difficulties.
- Identified PC and CS in natural flows (Figure 2b).

RESULTS

We have established that suspensions can organize themselves to rapidly deposit material at riverine sediment concentrations commonly measured on tectonically active margins (i.e., 300-1000 mg/l). Through the use of dimensional analysis and an exhaustive set of experiments, we have identified a scaling relationship, which collapses the laboratory data (Figure 1a; McCool and Parsons, in review). We have used this relationship to successfully predict effective settling rates observed on the Eel River margin during the STRATAFORM program (Figure 1b; McCool and Parsons, in review). The concentrations examined in this course of experiments were also substantially less than what has been known to initiate CS in the past (10 g/l: Maxworthy, 1999; 1 g/l: Parsons et al., 2001).

Preliminary evidence of PC, the ability of a turbulent suspension to produce areas of high and low concentration, emerged from analysis of sediment deposited in the saline basin (Figure 2a). In the experiments, fine material (<10 mm) was preferentially removed from the water column in the basin section. Using a simple analysis and relationships proposed by other workers (e.g., Hogan and Cuzzi, 2001), we were able to link this observation with the presence of PC in our experiments (Parsons and McCool, in review).

Final design of a new experimental facility investigating a realistic river plume has been completed. Construction is still underway because of delays related to the improvement of our lab space. Meanwhile, we have identified other natural settings where PC and CS are present (Figure 2b). These observations underscore the potential importance of these processes, not only to the oceanographic community, but to any environmental scientist or engineer studying particulate transport. We have developed strategies for documentation of PC and CS in braided rivers and the data acquired will be presented at the upcoming GSA Annual Meeting (November, 2003). Up until now, our measurements have been confined to subaerial environments, but future work will adapt these approaches to easily accessible nearshore locations (e.g., Skagit River plume in western Washington).

IMPACT/APPLICATIONS

The discovery of convective transport processes in turbulent fluids at concentrations less 1 g/l represents a significant scientific finding. Most rivers (even benign, passive-margin rivers) produce these concentrations during floods. Though mouth geometry and tidal characteristics may diminish the prevalence of CS in low-energy (passive-margin) rivers, there are numerous situations where

conditions will be favorable for this transport mode, particularly when considering ancient environments. For instance, modern low-latitude rivers produce ~ 1 g/l consistently and for long durations. In these systems, distribution of material is most likely controlled by the interreaction of CS with large-scale currents (e.g., Papua New Guinea: Kineke et al., 2000). Wet, temperate, unadulterated watersheds may also represent an environment affected by CS and PC, though ultimate deposition may be regulated by other hydrographic processes (e.g., Parsons et al., 2003; Puig et al., 2003).

Another significant finding is the sorting of material by particle-turbulence interactions. Though the stratigraphic signal of the sorting may be lost due to aggregation effects in nearshore environments, the process we observed may have important industrial applications (e.g., Cardoso and Zarrebini, 2001). Future work will attempt to identify if this sorting has a significant effect on floc growth and the distribution of sediments along the continental margin.

The empirical relationships based upon the laboratory experiments and scaling analyses provide numerical modelers with the capability of integrating small-scale particle-turbulence interactions into their models. Ongoing collaboration with Jasim Imran (University of South Carolina) will incorporate our simple relations into his large-scale models of river plume dynamics. Similar discussions are ongoing with Courtney Harris and her implementation of a Regional Ocean Model System (ROMS) in conjunction with workers at SCALANT.

TRANSITIONS

We believe that the simple CS models we are developing will be used in conjunction with the margin models being developed to predict margin morphology and stratigraphy (e.g., Syvitski and Hutton, 2001; Kassem and Imran, 2001). Our results should help guide observations made by other field workers outside of EuroSTRATAFORM and enable them to develop strategies for the observation of sediment-concentration variability and particulate transport in natural systems.

RELATED PROJECTS

This project is closely related to experiments investigating the interactions of surface gravity waves and high-density, near-bed suspensions. NSF recently funded the continuation of these experiments. Details about the experiments and associated fieldwork in ancient rocks can be found at: <http://www.ocean.washington.edu/people/faculty/parsons/research>.

The simplified models produced from our results will be used in conjunction with numerical models produced by Jasim Imran and James Syvitski, for ultimate use in *Sedflux*. We also have an ongoing collaboration with Courtney Harris to work on ways to implement the formulations we have posed in her ROMS model.

A recently funded NSF Major Research Instrumentation project (with Andrea Ogston) specifically addresses the needs of both laboratory and field instrumentation. As a part of this project, we are constructing a probe that can measure an array of points in the water column (~ 20), each with an extremely small sampling volume (e.g., 1 cm^3). The probe is still being constructed, but a prototype should be ready for use in our experiments by early 2004.

REFERENCES

- Cardoso, S. S. S. and Zarrebini, M. 2001. Sedimentation of polydispersed particles from a turbulent plume. *Chemical Engineering Science*, vol. 56, p. 4725-4736.
- Hill, P. S., Milligan, T. G., and Geyer, W. R. 2000. Controls on effective settling velocity of suspended sediment in the Eel River flood plume. *Continental Shelf Research*, vol. 20, p. 2095-2111.
- Hogan, R. C. and Cuzzi, J. N. 2001. Stokes and Reynolds number dependence of preferential particle concentration in simulated three-dimensional turbulence. *Physics of Fluids*, vol. 13, p. 2938-2945.
- Kassem, A. and Imran, J. 2001. Simulation of turbid underflows generated by the plunging of a river. *Geology*, vol. 29, p. 655-658.
- Kineke, G., Woolfe, K.J., Kuehl, S.A., Milliman, J., Dellapenna, T.M., and Purdon, R.G. 2000. Sediment export from the Sepik River, Papua New Guinea: Evidence for a divergent dispersal system. *Continental Shelf Research*, vol. 20, p. 2239-2266.
- Maxworthy, T. 1999. The dynamics of sedimenting surface gravity currents. *Journal of Fluid Mechanics*, vol. 392, p. 27-44.
- Parsons, J. D., Bush, J. W. M., and Syvitski, J. P. M. 2001. Hyperpycnal plumes with small sediment concentrations. *Sedimentology*, vol. 48, p. 465-478.
- Syvitski, J. P. M., and Hutton, E. W. H. 2001. 2D-SEDFLUX 1.0C: An advanced process-response numerical model for the fill of marine sedimentary basins. *Computers and Geoscience*, vol. 27, p. 731-753.

PUBLICATIONS

- McCool, W. W. and Parsons, J. D. Sedimentation from buoyant fine-grained suspensions. *Continental Shelf Research* [in review]
- Parsons, J. D., Friedrichs, C. T., Mohrig, D., Traykovski, P., Imran, J., Syvitski, J. P. M., Parker, G., Puig, P., Buttles, J., and Garcia, M. H. The mechanics of marine sediment gravity flows. In: *Continental Margin Sedimentation: Transport to Sequence*, eds. Nittrouer, C., Austin, J., Field, M., Steckler, M., Syvitski, J. and Wiberg, P. [in review]
- Parsons, J. D. and McCool, W. W. Experimental evidence of particle-size sorting due to preferential concentration in polydisperse turbulent suspensions. *Physics of Fluids* [in review]
- Parsons, J. D., Mullenbach, B. L., Lamb, M. P., and Finlayson, D. P. 2003. The role of turbidity currents in the creation of a distributary channel on the Eel River margin, northern California. *GSA Bulletin*, vol. 115 [in press]

Puig, P., Ogston, A. S., Mullenbach, B. L., Nittrouer, C. A., Parsons, J. D., and Sternberg, R. W. 2003. Storm-induced sediment-gravity flows at the head of the Eel submarine canyon. Journal of Geophysical Research [in press]

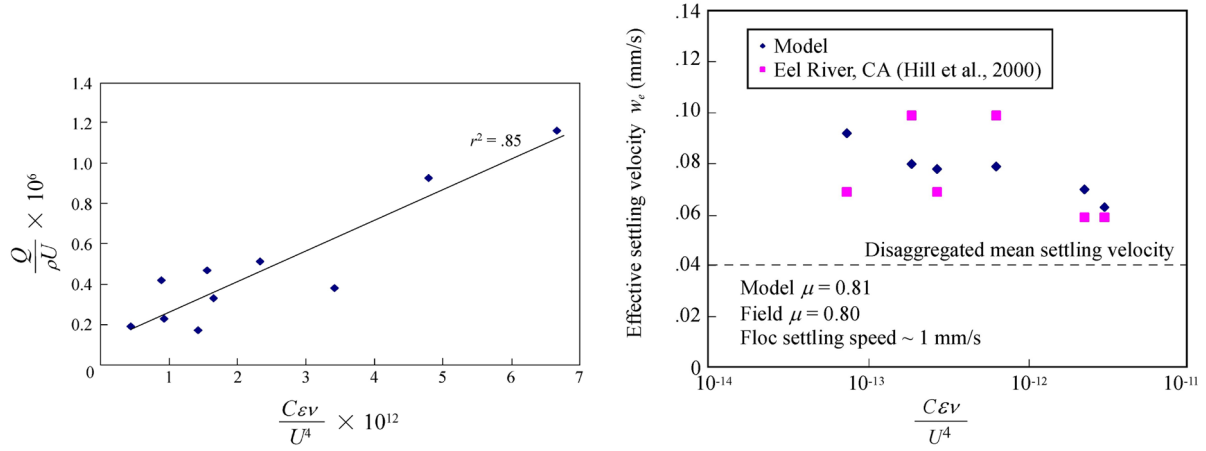


Figure 1a) Left: Collapse of experimental data with our proposed scaling relationship. The vertical sediment flux Q is made dimensionless by the plume velocity U and the density of interstitial fluid ρ . Other parameters of interest are the volumetric concentration of sediment within the plume C , the turbulent dissipation rate ε , and the kinematic viscosity ν . **b) Right:** Comparison of our proposed relation (model) with data obtained from the Eel River margin during STRATAFORM (Hill et al., 2000). As noted in the figure, effective settling rates were not well predicted by individual floc or disaggregated settling speeds.

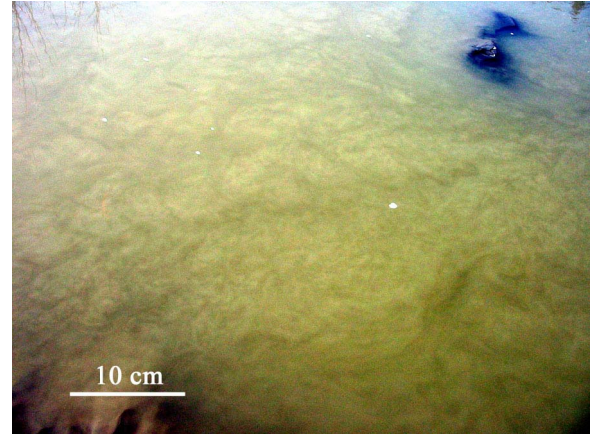
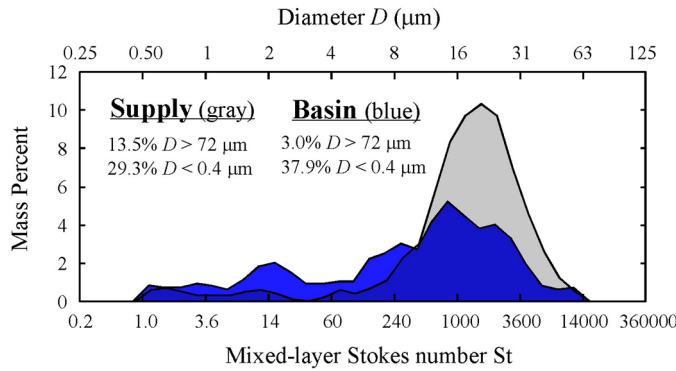


Figure 2a) Left: A comparison of the input and the material settled by convective processes. The light blue area indicates an enrichment of particles of diameters $0.5 < D < 10 \mu\text{m}$. The Stokes number St is defined by the ratio of the turbulent time-scale (Kolmogorov time-scale) divided by the particle response time. When the St is near unity, PC is maximized, indicating that the convective plumes observed in our experiments were formed partly as a result of PC. **b) Right:** Photograph of the Toutle River in the spring of 2001. The variability of lighting in the stream is associated with increased backscattered light in areas of higher sediment concentration. These preferentially concentrated areas are consistent with small-scale eddies and the processes responsible for PC. The sediment in the Toutle is predominantly silt, with $St \sim 1$.